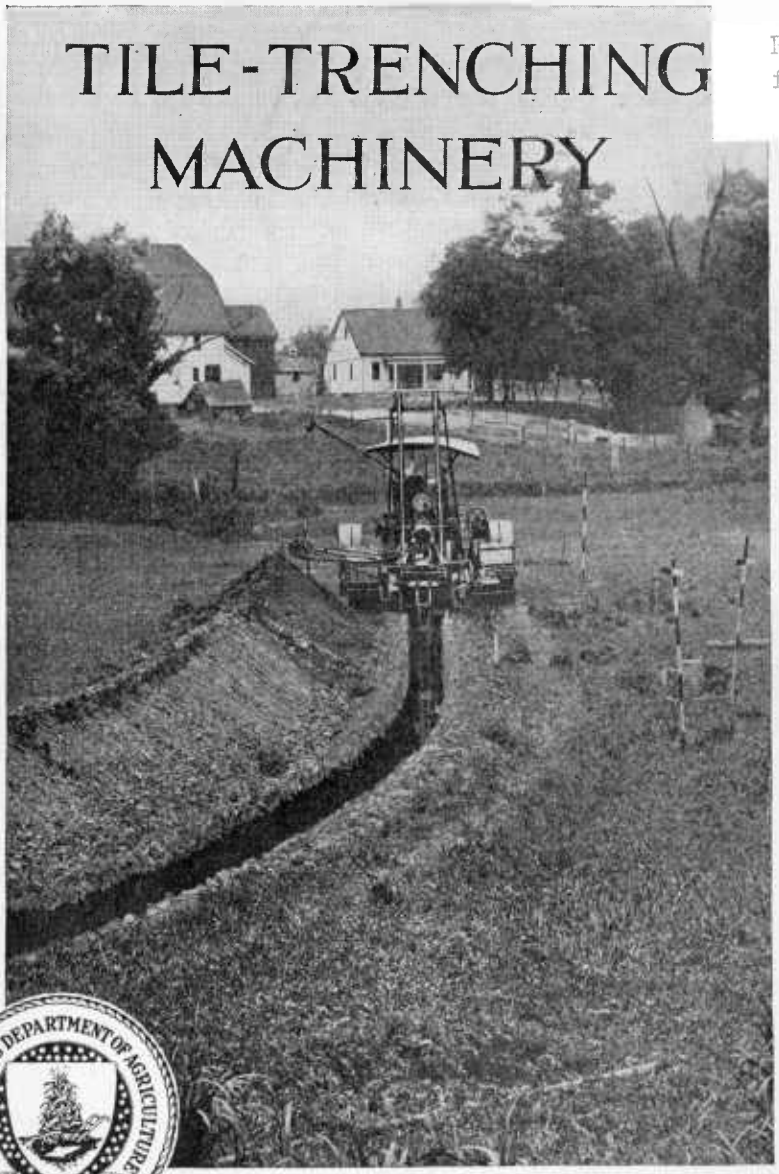
U. S. DEPARTMENT OF AGRICULTURE

FARMERS' BULLETIN No. 1131 rev. Nov. 1925

Rev.ed. follows

TILE-TRENCHING MACHINERY



THE MORE EXTENSIVE use of tile-trenching machinery has been brought about by the rising prices and increasing scarcity of labor and the rapid extension of tile drainage for farm lands to increase crop production.

Tile-trenching machinery may be divided into two general classes—horse-drawn ditching plows and power-operated trenching machines.

The ditching plows are comparatively inexpensive implements, costing from $20 to $500, which will excavate trenches suitable for the smaller sizes of tile. Hand labor is necessary to grade the trench after using them.

Power-operated machines are of the following general types: Wheel excavators, endless-chain excavators, and those of the drag-line and dry-land, dipper-dredge types. The less expensive power machines, costing from $3,300 to $4,500, are used extensively on farm tile drainage. The larger sizes are adapted to contractors' use.

Devices for back-filling trenches range from the ordinary moldboard plow to power-driven back fillers.

The cost of trenching by machinery is not greatly different from that of handwork. The main advantages of machine work over hand labor are the fewer men required and the more rapid completion of the work.

Washington, D. C.

Issued May, 1920
Revised November, 1925

The names and addresses of the manufacturers of the various machines discussed in this bulletin will be furnished on application to the Bureau of Public Roads, Department of Agriculture, Washington, D. C.

TILE-TRENCHING MACHINERY

D. L. YARNELL

Drainage Engineer, Division of Agricultural Engineering, Bureau of Public Roads

THE INVENTION of suitable appliances for tile trenching has been stimulated by various agencies—the rising prices and increasing scarcity of labor, the rapid extension of tile drainage for farm lands to increase crop production, and the growing practice of using large tile instead of open ditches of moderate size for community outlets, especially where the depth of cut is rather great. Where wide trenches are dug by hand deeper than 6 or 7 feet, the material must be handled at least twice, since the dirt can not be thrown back from the edge of the trench at the first handling. Besides reducing the amount and cost of labor, a good machine greatly lessens the time necessary for doing the work, which is often of considerable advantage, apart from any saving in direct money cost. Difficulties such as occasionally arise where many unskilled workmen are employed may be largely avoided by the use of machinery requiring only a small crew. The many types of equipment for trenching vary from horse-drawn machines of small size to elaborate power-driven machines costing thousands of dollars. The various types of ditching plows are limited as to the depth and width of trench they will cut, also in regard to the conditions under which they will work.

REQUISITES OF A GOOD MACHINE

Three things are required of a good trenching machine, namely, (1) it must operate efficiently through various kinds of soil; (2) it must be capable of cutting true to grade; (3) it must work for long periods without breaking or otherwise getting out of order. The first of these requirements is the hardest to fulfill; the second is the easiest.

There are many kinds of soil to be encountered—hard shale, cemented gravel, sand, stones, loose loam, soft muck, and sticky clay. None of the machines will handle solid rock. The ideal machine will handle all kinds of soil, with but minor changes of parts, without breaking or stopping and at a minimum expense for purchase, operation, repairs, and depreciation. Open or skeleton excavating buck-

ets are best suited to sticky soils, while solid buckets are necessary in loose, dry soils, though some machines have efficient cleaning devices that permit the use of solid buckets for any kind of material. A machine must be strong to work through shale or stony ground, but if increased strength entails added weight its efficiency and adaptability may be affected. A heavy machine can not work over soft ground unless fitted with rather costly apron tractors instead of the driving wheels.

GENERAL CLASSES OF TRENCHING MACHINES

The many types of trenching machines may be divided into four general classes: (1) Plows and scoops, (2) wheel excavators, (3) endless-chain excavators, (4) scraper excavators. The general nature of the plows and scoops is indicated by their names. They are usually operated by horses, and some merely loosen the dirt to make hand shoveling easier. In the wheel excavators the excavating buckets are arranged upon the rim of a wheel. (See fig. 7.) In the endless-chain excavators the excavating buckets are carried on parallel endless chains supported by a long steel frame at the rear of the machine. One end of the frame is lowered so that the buckets are drawn up the end of the trench, cutting a thin slice of earth from the bottom to the top. (See fig. 10) The scraper machines are the same as the drag-line machines designed for wide ditches, sometimes with slight changes in the rigging to give better control of the bucket.

The dry-land dipper dredges are of the type ordinarily used in the construction of open ditches. The largest machines of the third and fourth classes are adapted to deeper and wider trenching than are those of the other classes.

In the following descriptions of the various types the letters used to designate the machines have been assigned arbitrarily by the writer for convenient reference. The prices given are those quoted during the spring of 1923.

DITCHING PLOWS[1]

This class of excavators has been made to include the smaller and less expensive implements, which will be found economical for smaller jobs than would warrant the purchase of the more costly machines. All the plows are lacking in any device for cutting accurately to grade. Some handwork is necessary to make the trench smooth for laying the tile properly. Many are limited in depth of digging to 2½ or 3 feet, which in many places is not as deep as tile should be laid. Some of these implements are merely aids to handwork, using animal power only to loosen the dirt. The main advantage over the more elaborate trenching machines is their low cost. (See Farmers' Bulletin No. 524, for information on digging trenches for small fields entailing handwork.)

The ditching plow is essentially a farm tool, adapted to the needs of the farmer who wishes to drain a portion of his farm. By using plows he can to a certain extent substitute horse power for man power. If the drains are so located that they can be constructed

[1] The data on horse-drawn plows have been abstracted from a report by F. F. Shafer, associate drainage engineer, Bureau of Public Roads.

at times when farm work is not pressing, the horses unemployed, and the farm labor free to do most of the handwork, the tiles can be laid quite cheaply. For large jobs, or contract work, hand labor or power ditchers are probably preferable.

The ditching plows will not work on lands so wet or boggy that horses can not be driven over them. In wet, loose, or sandy soils it may be necessary to use extra wide eveners that the horses may walk some distance away from and on each side of the trench, and thus the banks of the trench are not so apt to be broken down. Attempts to use tractors for operating ditching plows have in some instances failed because the weight of the tractor broke down the banks of the trench.

In constructing tile drains it is always desirable to open up only a comparatively short length of trench at one time, for if bad weather occurs the walls of the trench are apt to cave or wash, and much additional labor will be required to get the trench in condition to lay the tile. If, however, the plow is to be used to the best advantage, it is necessary to open up the entire length of a drain, or possibly several drains at one time. Tile should always be laid and blinded as fast as the trenches are finished to grade.

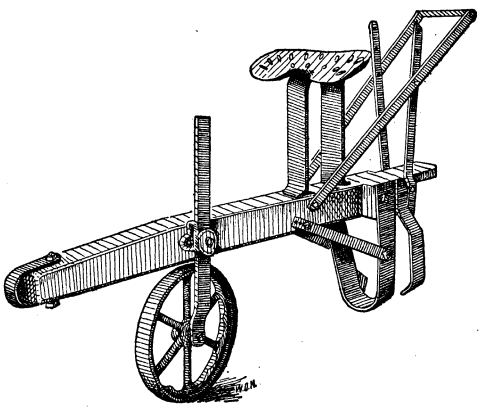


FIG. 1.—Ditching plow A used for loosening soil in trenches.

DITCHING PLOW A

Perhaps one of the simplest trenching devices is the ditching plow shown in figure 1, which is used only to loosen the dirt in order that shoveling may be easier. The U-shaped knife does most of the cutting; the side knives just behind keep the sides of the trench vertical. Each plowing cuts from 1 to 6 inches deep, depending upon the hardness of the soil. After each round of the plow the loosened material is thrown out with shovels. The usual width of the trench is about 12 inches, but the side knives may be spread to cut 16 inches wide. This plow weighs about 165 pounds and costs about $20. It is drawn by two horses. One man holds the plow and another drives the team. The trench must be graded with hand labor.

DITCHING PLOW B

Figure 2 shows another ditching plow for merely loosening the soil. The first furrow along the trench is made with an ordinary plow, then the ditching implement is used. This plow has no moldboard, and the share cuts 6 inches wide on the bottom. An adjustable slider in front of the plowpoint regulates the depth of each cutting. The plow beam is adjustable vertically, being pivoted on the front arm of the standard and held in the desired position by a segment at the rear end of the beam. The first round of this plow

cuts the sides of the trench straight down. The loose earth is then shoveled out, the plow beam is raised, and another round is made. This process is repeated until the desired depth is reached. The minimum width of trench is 8 inches, and the plow works in this width to 3 feet deep without difficulty. Wider trenches can be cut deeper, though it may be necessary to lengthen the distance between the plow and the team. An attachment is made for cutting a smooth groove in the bottom of the trench, in which to lay the tile, but there is no way of cutting to grade with this implement, and the trench must be finished with hand labor. The plow weighs about 150 pounds and costs about $20. It is drawn by two horses. One man is required to drive the horses and one to handle the plow.

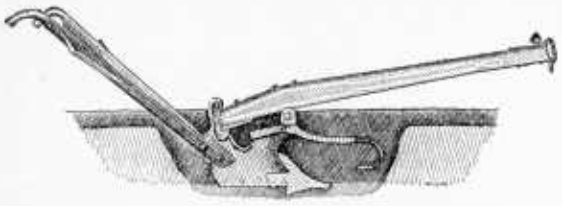


FIG. 2.—Ditching plow B for loosening soil in trenches.

DITCHING PLOW C

Ditching plow C (see fig. 3) is mounted on wheels; the two smaller wheels run in the trench and the two larger ones straddle the trench. At the point of the plow is a U-shaped cutting bail which shapes the trench. The earth is pushed up the moldboard to the top of the trench on the right side only, while an extended wing on the left side drags the dirt back from the trench on the return trip. The dirt is removed by driving back and forth on the trench. The full depth of the trench is not made at one cutting, but from 1 to 6 inches is

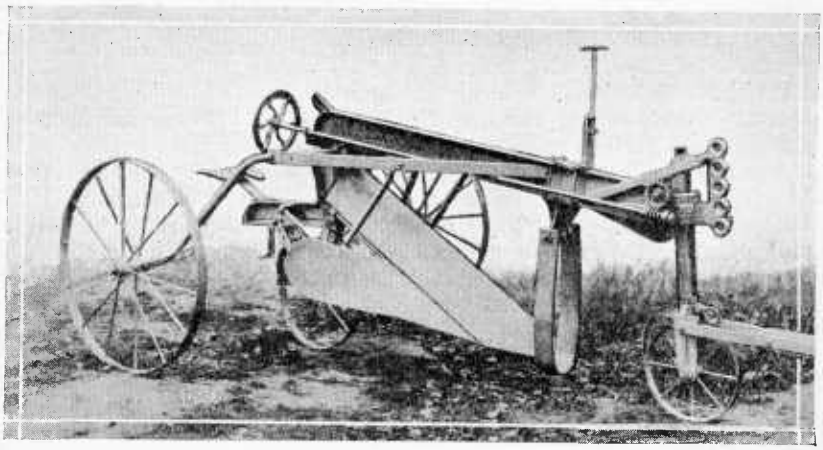


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FIG. 3.—Ditching plow C for constructing trenches not more than three feet deep.

removed at each passage. The trench is 12 inches wide and the maximum depth possible is 3 feet. From four to six horses and three men are required to operate the plow. The machine will cut about 150 rods of trench, from 24 to 30 inches deep, in 10 hours. Hand-

work is required to finish the trench to grade for laying the tile. The implement weighs about 1,200 pounds and costs $515.

DITCHING PLOW D.

At first glance ditching plow D (fig. 4) looks something like a wheel excavator, but it is merely a plow fitted with a wheel and belt for lifting out of the trench the dirt loosened by the plow. The plow is located under the rear of the elevating wheel, which bears the entire weight of the machine when working. The frame of the machine is lowered until the plow cuts a slice of earth 1 to 6 inches thick, according to the kind and condition of soil. The driver from the rear seat controls the thickness of this slice by levers that change the distance of the plowpoint from the rim of the elevating wheel. This wheel has a wide rim, with flanges about 3 inches deep, between

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FIG. 4.—Ditching plow D for constructing trenches up to three feet deep.

which the 8-inch link belt fits easily. The elevating wheel is revolved by friction on the ground, and drives the link belt by means of a chain connection. As the dirt is loosened by the plow it is caught between the wheel and belt and is carried to the top of the machine, where it is forced off the wheel upon a dirt board that drops it beside the trench. The flanges of the large wheel act as rolling cutters in trimming the sides of the trench. The belt is kept taut by a small movable pulley and a steel spring under the rear driving seat. When one slice has been taken from the bottom of the trench, the frame of the machine, with plow, wheel, and belt, is further lowered and another slice is cut. This process is continued until the trench is as deep as is desired, or until the maximum depth that the machine will cut (36 inches) has been reached. Handwork is required to bring the trench to exact grade.

Operated in the manner described, this excavator will dig a trench about 10 inches wide, or wide enough for 6-inch tile. The machine can be equipped with two trimming knives for cutting wider trenches. These knives are made in different sizes, for digging trenches up to 16 inches wide. As the trimming knives are behind the plow the dirt which they loosen is not removed until the machine makes the next cut through the trench. The dirt board may be raised or lowered to regulate, in a measure, the distance at which the excavated material is placed from the trench. Usually one man and four horses are needed for operating this plow, although sometimes an extra man is needed for driving until the horses become accustomed to the work. An average day's work with this machine would be about 150 rods of trench, 30 to 36 inches deep. The excavator weighs about a ton and costs $425.

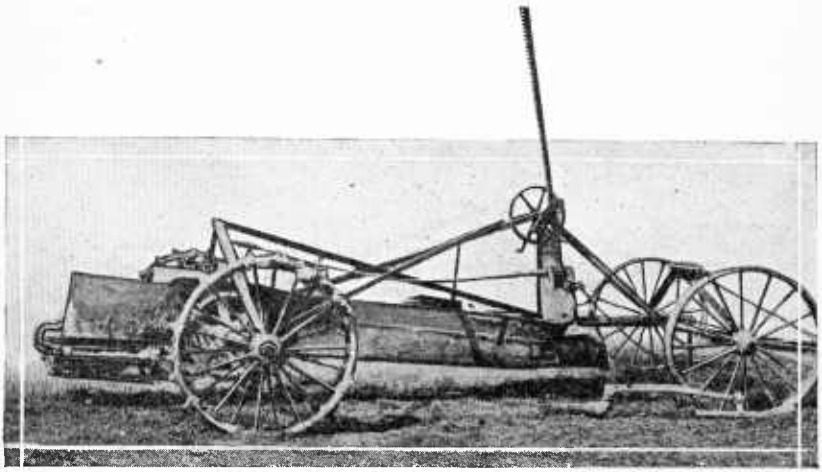

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FIG. 5.—Ditching plow E which will construct trenches not exceeding 54 inches deep.

DITCHING PLOW E

The mechanism of ditching plow E (see fig. 5) consists of a long, inclined U-shaped trough, in which travels a metal continuous-chain dirt carrier. Attached to the front end of the trough is a steel U-shaped cutting bail which does the digging. The cutting edge is raised and lowered in a vertical line by a graduated iron rod. One edge of the rod has a rack into which meshes a gear operated by a handwheel. A change of position of the cutting bail one notch represents one-tenth of a foot.

The back end of the dirt carrier is supported by the rear axle of the machine, which furnishes the power to elevate the dirt. The earth is dumped from the inclined carrier onto a short side carrier which deposits it one side of the trench. The driving power for the elevating carrier and the delivery conveyor is obtained from the rear wheels of the machine, these wheels being equipped with lugs to prevent slipping. The wheels have a tread of about 10 feet to permit them to travel outside of the dirt removed.

The dirt is removed by driving back and forth over the trench, cutting from 3 to 6 inches at each cut. The machine will cut a trench 12 inches wide and of any depth up to 54 inches. Three men and from six to eight horses are required for operating the machine. The implement has no device for cutting to an accurate grade; consequently some handwork is required to finish the trench to exact grade. This plow under average working conditions will dig about 150 rods of trench, 3 feet deep, in a day. The price is approximately $500.

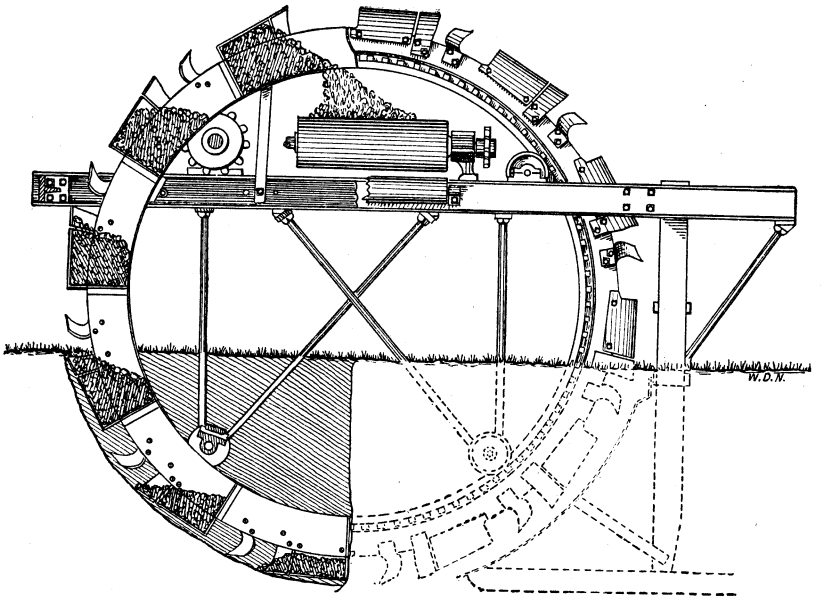

FIG. 6.—Digging mechanism of a common type of wheel excavator.

WHEEL EXCAVATORS

COMMON FEATURES

The wheel excavators generally have steel bed frames, rigidly braced, upon which the power equipment is mounted. Internal-combustion engines burning gasoline, kerosene, naphtha, or alcohol are perhaps most generally used, though steam engines and boilers are often preferred. The internal-combustion engines are preferable where it is important to avoid unnecessary weight.

The machine usually is supported upon two pairs of wheels, the front pair with flanges to prevent slipping sidewise from the line of the trench. The rear wheels carry most of the weight and therefore are large and broad. Many manufacturers now fit their machines, especially the heavier ones, with what are known as apron or caterpillar tractors (see figs. 7, 8, and 10) instead of rear wheels. Each of these tractors consists of a series of wooden or iron crosspieces carried by parallel endless chains about a steel frame in such manner that the weight of the machine rests upon several crosspieces; the large bearing surface thus obtained will support the machine upon very soft ground. As the excavator moves forward the chains lift the crosspieces at the rear and carry them to the front of the tractor.

Most machines move by applying power directly to turn the rear wheels or tractors. In soft soils, when power is applied to the wheels or tractors, these often slip and the consequent "churning" causes the trench banks to cave and the machines to settle deep into the ground. When a tile-laying shield must be used the amount of power necessary to move the machine may make it difficult to apply power directly to the tractors on the very large machines, in which case it may be advisable to pull the machine ahead by a cable anchored to a "dead man." By pulling the machine ahead the load on the ditch bank is decreased, which may prevent caving of soft soils.

The digging is done by buckets upon the rim of a wheel that is revolved in the trench (fig. 6), and as each bucket reaches the top of the circle the dirt falls upon a conveyor belt that can be shifted to deposit the soil upon either side of the trench.

Levers are so arranged that the depth of excavation can be accurately controlled by the person operating the machine. An arm or gauge is attached to the digging frame in such a way that the operator can sight across it to targets set along the line of the trench at a known height above the desired bottom, and can thus cut true to grade.

For work in soils so soft that the sides of the trench will not stand unless supported, some machines may be fitted with shields following close behind the digging apparatus, which keep the trench open until the tile can be placed in position. The shields for the smaller machines are usually about 8 feet long, just sufficient to permit a man using a tile hook to lay the tile properly. The use of the shield, of course, increases the amount of power necessary to draw the machine ahead. The caving earth frequently causes the last-laid tile to "creep" forward with the machine, leaving an opening between tiles where much dirt might get into the drain and choke it. To prevent this creeping, the man laying the tile must hold the tile in place until it has left the shield. The shields on the large machines are of sufficient width for a man to work in them.

Unstable soils often cave in at the sides of the digging wheels. To prevent this the manufacturers provide a casing for the digging wheel. The additional cost of such a wheel casing is often justified, since it prevents the earth from caving into the trench at the wheel.

MACHINE F

The machine of this class in most common use (see fig. 7) has an open excavating wheel; that is, a wheel with neither spokes nor hub. This wheel consists of two parallel iron rims held in their proper relative position by the buckets, which are fixed between the rims and firmly riveted to them. The rims are supported upon four pairs of small wheels (see fig. 6). Both wheels of the pair just above the point where the digging is done are sprocket wheels, through which the power is applied. The buckets are open at the inner side, but close inside the rims is a metal plate extending nearly one-half the circumference of the excavating wheel that keeps the dirt in the buckets until it has been carried to the highest point; there it falls upon a belt conveyor, which deposits the soil beside the trench. Between the buckets, which have semicircular cutting edges, side cutters (see fig. 6) are bolted to the wheel for cutting the trench a

little wider than the buckets, thus reducing the friction. The front end of the frame carrying the excavating wheel is hinged to the rear of the platform carrying the power equipment; the rear of the frame is supported on a shoe that slides on the bottom of the trench and makes a smooth, shallow groove for the tile. The maximum depth of digging is about two-thirds the diameter of the wheel. Solid buckets are used for digging light or sandy soils and skeleton buckets for the wet and sticky soils, as the latter buckets are easier to clean. A cleaning device is furnished to remove sticky earth from the buckets.

This machine is made in several sizes, and digs trenches ranging from 11½ inches wide by 4½ feet deep to 18 inches wide by 6½ feet deep. The weights and approximate selling prices for this machine, equipped with internal-combustion engines and wheel traction, are as follows:

Sizes, weights, and costs of machine F.

Size of trench.	Power equipment.	Weight (tons).	Price.
11½ inches by 4½ feet	14 horsepower, single cylinder	7½	$3,300
11½ inches by 4½ feet	20 horsepower, 4-cylinder	7	4,400
11½ inches by 5½ feet	14 horsepower, single cylinder	7	3,700
11½ inches by 5½ feet	20 horsepower, 4-cylinder	8	4,500
15 and 18 inches by 5½ feet	20 horsepower, 4-cylinder	12	4,800
15 and 18 inches by 6½ feet	30 horsepower, 4-cylinder	13¾	5,700

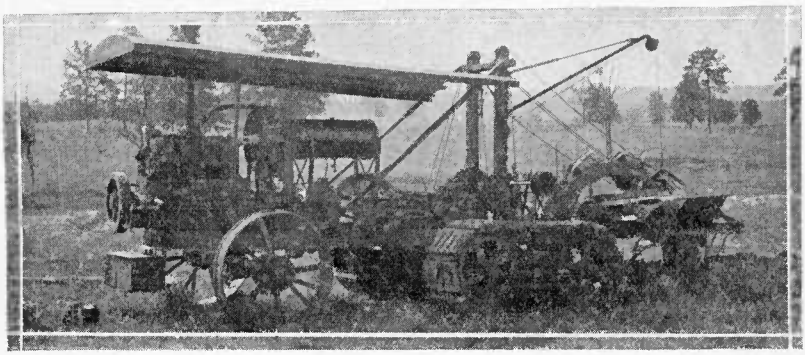

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FIG. 7.—Wheel machine F equipped with a four-cylinder, internal-combustion engine, and apron wheels. This size of machine cuts a trench 11½ inches wide, 4½ feet deep at one operation.

To equip any of these sizes with apron wheels an additional charge of from $250 to $300 is made. The trenching shields and the wheel casings each cost from $35 to $65 extra. The apron wheels increase the above weights by about 2,500 pounds. The machine is equipped with various gears for regulating the forward movement, which is accomplished by power applied to the rear wheels of tractors. The road speed is about 2 miles an hour. For railroad transportation the wheels or tractors must be removed from the larger sizes.

The cutting speed of these machines varies from 1 to 8 feet per minute. In beginning a trench the forward end of the cutting-wheel frame should be about 3½ feet lower than the rear end. The traction is then thrown in, and as the machine moves forward the wheel cuts

its way forward and downward at this angle until grade is reached. The digging-wheel frame is leveled and grade is maintained by raising or lowering the forward end of the frame by a power hoist. The smaller machines are provided with a friction safety device which slips when an obstacle is met. On the larger machines the multiple-disk clutch forms the safety device. A sight arm is provided for digging to grade. A careful operator can attain very satisfactory grades with this machine. One man is required to operate it.

A large number of these machines have been manufactured and have given general satisfaction under ordinary soil conditions. They have cut tree roots as large as a man's arm. Stones larger than the buckets will be rolled out if found near the surface of the ground, but when bedded deeply they must be removed by hand. Ordinarily it is not wise to attempt to cut large roots or remove large stones with the machine, as it strains it unnecessarily.

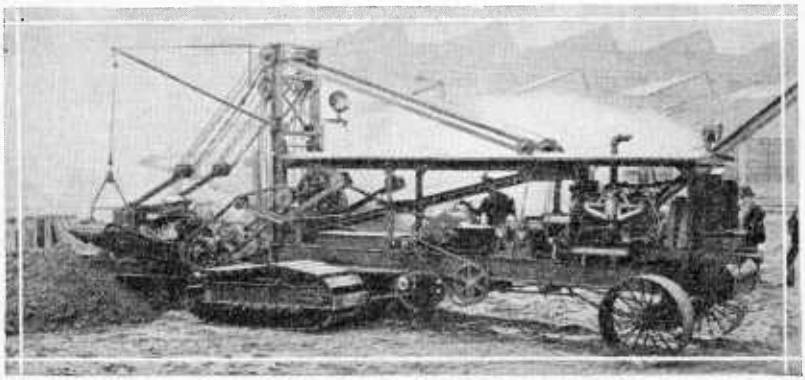

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FIG. 8.—Wheel machine G. This size of machine cuts a trench 15 inches to 21 inches wide, 6 feet deep at one operation.

MACHINE G

A type of wheel excavator which has buckets somewhat different from those of machine F is manufactured (see fig. 8). Each of the buckets is a broad, low T with an arched top, attached by the vertical stem to a rib on the wide rim of the excavating wheel. The buckets are open at the sides. Two stationary cleaners, one on each side at the top of the wheel, scrape the dirt from the buckets onto a belt conveyor, which deposits it on the side of the trench. These buckets were designed for very sticky soils, and for work in loose material are fitted with spring backs. Only one man is required to operate the machine.

This machine is made in two sizes. It digs trenches from 12½ inches wide by 4½ feet deep to 24 inches wide by 7½ feet deep. Its approximate selling prices, when equipped with internal-combustion engine, an apron or corduroy traction, wheel casing, and shield are as follows:

Sizes and prices of machine F.

15 to 21 inches by 6½ feet, 30-horsepower 4-cylinder engine	$7,400
20 to 24 inches by 7½ feet, 45-horsepower 4-cylinder engine	13,200

ENDLESS-CHAIN EXCAVATORS.

This class of excavator, like the wheel machines, has a steel bed frame mounted upon two pairs of wheels and carrying steam engines and boilers or internal-combustion engines. Apron tractors are often used instead of the rear wheels. The digging apparatus is operated by a wheel at the upper end of the frame, receiving power through a chain or belt drive from the engine (see fig. 9). At the end of their upward movement the buckets empty their loads upon an endless belt, which conveys the dirt far enough to the side that it will not fall

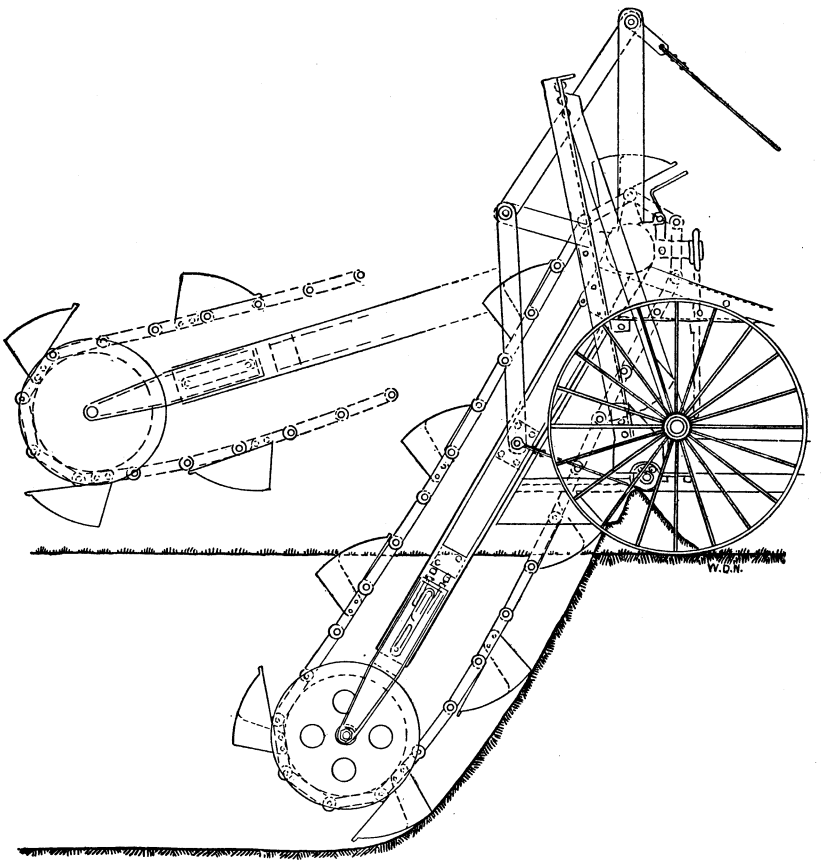

FIG. 9.—Digging mechanism of a common type of endless-chain excavators.

back into the trench. Cutting knives or teeth on the lip of the bucket are often used in hard ground.

Devices for cleaning the buckets are provided. The depth of excavation is regulated by levers in the same way as for the wheel excavators. Shields can be used to keep the trench from caving until the tile have been laid.

MACHINE H

This excavator (see fig. 10) carries most of the weight on two tractors, each of 10 to 50 square feet bearing surface, depending upon the size of the machine and the character of the soil. The

front wheels guide the machine and carry a little weight. The usual power equipment is a gasoline engine of the vertical, water-cooled type, with two to four cylinders. This is belt-connected to a friction drum, which transmits the power through a heavy sprocket chain to the excavating chain and the belt conveyor. The gasoline and water tanks are located ahead of the engine on the front of the bed frame. The machine moves forward by power applied directly to the tractors. Its average road speed is about 2 miles per hour. The manufacturers of this machine provide a device that prevents soft earth from working up between the boards forming the bearing surface of the tractor, eliminating a source of annoyance not uncommon to apron tractors generally. The excavating buckets are of the open, conical-scoop shape; and as each revolves about the driving wheel, it is scraped by a cleaning device that causes the dirt to fall upon the belt conveyor. This conveyor can easily be shifted from one side to the other, permitting the dirt to be piled on the side preferred.

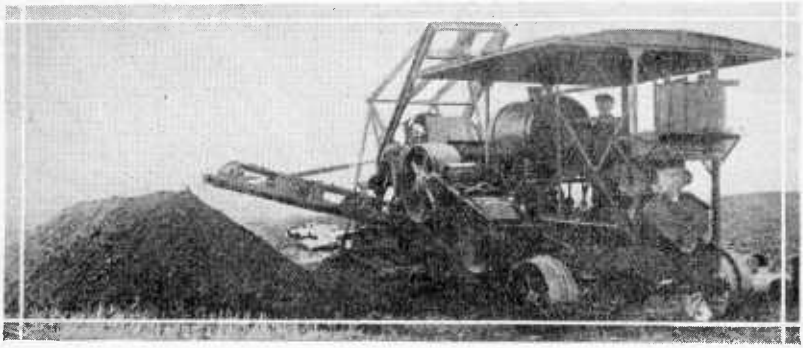

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FIG. 10.—Endless-chain machine H, equipped with apron traction. This size cuts a trench 18 inches wide 9 feet deep at one operation.

The machine is made in various sizes, the smallest digging 15 to 18 inches wide and any depth not exceeding 5 feet, the largest digging 18 to 30 inches wide and any depth to 15 feet. The operator can adjust the width of the trench merely by changing the knives or reamers used with the buckets. The size of machine most used for farm drainage digs a trench 9 feet deep and 18 inches wide. This machine, equipped with a 25-horsepower 4-cylinder internal-combustion engine, weighs $11\frac{1}{4}$ tons, and costs $6,800. It is mounted on caterpillars giving a total bearing surface of approximately 3,750 square inches. Only one man is needed to operate the machine.

MACHINE I

Another machine of the endless-chain type is shown in figure 11. This machine cuts a trench from 15 to 24 inches wide and any depth not exceeding 10 feet. The machine is equipped with tractors and is operated by a 28-horsepower 4-cylinder gasoline engine. The road speed of the machine is $1\frac{1}{2}$ miles per hour and the digging speed from 8 to 10 feet per minute. The machine can be shipped without dis-

mantling on one flat car. A grading device is furnished for cutting the trench to the desired grade. Only one man is required to operate the machine. The excavator weighs 8½ tons and costs $6,200.

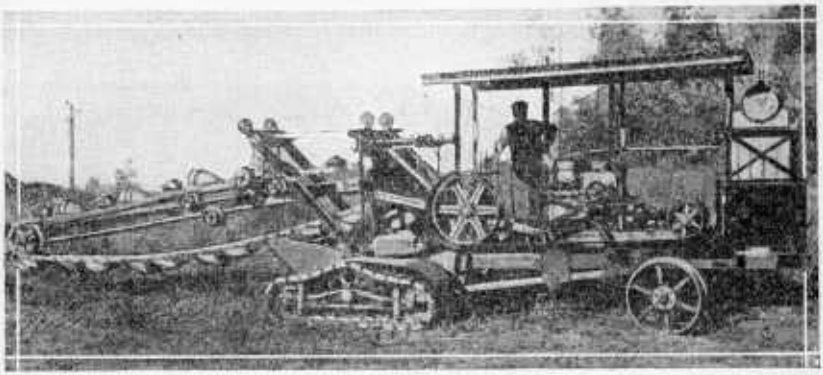

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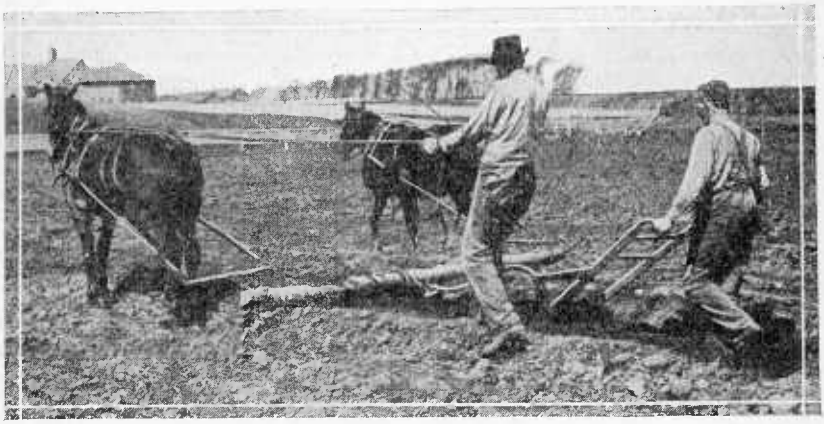
FIG. 11.—Endless-chain machine 1, boom in position for traveling. This machine digs 15, 18, and 24 inches wide and 10 feet deep.

BACK-FILLING DEVICES

For back filling the trench both horse-drawn and power-operated implements may be used. For the smaller and shallower trenches the common method is by means of an ordinary moldboard plow



B. P. R. D-2393

FIG. 12.—Back filling a tile trench with team and plow.

(fig. 12). The V-shaped drag operated by horses may also be used. By driving back and forth along the trench the material is dragged back into the point of the drag and drops into the trench. The com-

mon slip scraper is occasionally used to back-fill trenches. A road grader or a steel-bladed scraper (see fig. 13), which is mounted on wheels and pulled by horses, may also be used. This machine costs about $75.

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FIG. 13.—Back filling a tile trench with team and small road grader.

For filling large trenches power-operated back-filling machines are rapidly coming into use. One type is shown in figure 14. This machine travels along one side of and parallel to the ditch. When all the material at one place has been deposited in the trench the

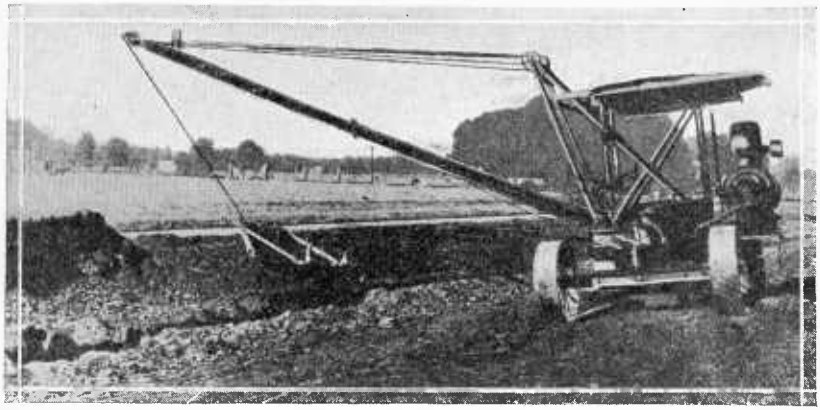

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FIG. 14.—Power-operated back filler filling a large tile trench.

machine moves ahead directly opposite the next section to be filled. The machine can move seven buckets of earth a minute into the trench. It is operated by a 10-horsepower gasoline engine and costs $2,240.

COST OF TRENCHING BY MACHINERY

The cost of trenching by machinery depends upon a number of factors, some of which often are overlooked in considering the purchase of such a machine.

The cost of operation per day will depend upon the number of men and teams employed, the wages paid, and the amount and cost of fuel. In respect to labor the internal-combustion engine has the advantage, for usually only one skilled operator is needed, while steam equipment requires also a fireman and a team with driver to haul fuel and water. It may be that not all of the workmen are paid when work is delayed by unfavorable conditions or for repairs; but the operator and frequently his helper are employed in making the repairs, and it may often be necessary to pay the men for time lost owing to such causes as rain. Laying tile, blinding,[2] and back filling the trenches of course require further labor, which would be the same for machine work as for hand labor. In farm tile-drain contracts only three items are usually covered—trenching, laying, and blinding.

The amount of work done per day will depend upon the soil conditions, the strength and efficiency of the machine, and the skill of the workmen. One of the most difficult soils to work is a wet, sticky clay; a sandy subsoil often will cause difficulty. The presence of large stones or thick tree roots will of course interfere greatly, more so than with hand ditching. Very hard subsoil may make progress slow. Some of the machines have worked through 15 inches of frost, but this is severe work for any trenching machine or excavator, as it subjects the machine to strains which it was not planned to withstand. Some clays become baked hard enough in dry periods to make trenching slow. These various conditions will show the weak points of a machine, and may cause a considerable variation in the cost of operation, due to the cost of new parts and repair work and the resultant loss of time.

It may be of interest to note a few instances of work by machines. In a saturated loam soil a machine of type F dug 105 rods of trench, 14½ inches wide and 40 inches deep, in 9 hours (an unusually good day's run). In a heavy, sticky clay, another machine of the same type dug 280 rods of 12-inch trench, 3½ to 5½ feet deep, at the rate of 61 rods in 10 hours, the best day's work being 91 rods.

The matter of lost time is of great importance, for the owner usually is losing money when his machine is not digging. The portion of a year during which a machine does not work is surprisingly great, even to many drainage contractors, and will explain why trenching with a machine costs so much more than one ordinarily would expect even after watching the machine work for several days under adverse conditions. While a machine is on the work there is loss due to stormy weather, and sometimes due to flooding of lowlands; there are delays for repairs, including waits for new machine parts; and there is time spent in moving from one trench to another. Interest and depreciation charges accrue during all these delays, as well as on Sundays and while the machine is being transported between jobs or lies idle waiting for new work. In the Northern States

[2] "Blinding" is carefully placing the first few inches of earth around and over the tile to hold it in position and protect it while the trench is being filled.

there are two to four months of the year when frozen ground and cold weather prevent work of this kind, except at rates too high for farm drainage. A contractor who has his machine actually digging 200 days in the year is fortunate.

It will be helpful to examine the record of one large contract on which the conditions were fairly good. The machine of type F arrived June 24 and began digging July 3; trenching was completed October 1. Of the 100 days the machine was on the job there were 14 Sundays, 61 days of machine work, and 25 days lost on account of repairs, rain, and miscellaneous delays. The main drain, of 5-inch to 12-inch tile, was 358 rods long and about 3.9 feet average depth. The lateral drains, of 4-inch and 5-inch tile, had a total length of 6,055 rods and an average depth of about 2½ feet. Of the 61 days of work, 12 were required for the main drain and 49 for the laterals. The average rates of progress, considering only the days of actual work, were 29.8 rods per day for the main drain and 123.6 rods per day for the laterals. If the 25 lost days be included, the working days actually used were 15 and 71 for the main and the laterals, respectively, and the average rates of digging are then computed as 23.9 and 85.3 rods per day. Coal was used as fuel, 24 short tons being required to dig 6,413 rods of ditch, or an average of 7½ pounds per rod of ditch. Repairs amounted to about 15 per cent of the cost of operation.

Another large machine [3] of type F dug from August 3 to December 7, 1918, 3,331 rods of trench in 636¾ operating hours, an average of 5.2 rods per hour. The machine was operated 10 hours a day for 6 week days. The time lost due to repairs was 221¾ hours; 9½ hours were lost on account of weather and 67 hours on account of moving between jobs on 40 different farms. The depth of trench varies as follows: 3,073.5 rods, 3 feet deep; 74 rods, 3½ feet deep; 130.5 rods, 4 feet deep; 36.5 rods, 4½ feet deep; and 18 rods, 5 feet deep. Some of the soil was quite stony. The amount spent for repairs was $241.27. The amount of gasoline used was 1,540 gallons, or an average of 1 gallon for 2.16 rods of trench dug. The gasoline cost $415.53; oil and grease cost $79.59. The machine crew consisted of one operator and one helper.

The average digging hours per 10-hour day of 15 State-owned machines operating in New York [3] during 1918 was only 4 hours, the remainder of the time being spent on repairs, delays on account of rock, and frequent moving between farms.

For tile trenching and laying by hand, where experienced men are employed, the rate of progress for one bottom man and one top man for the smaller sizes of tile laid not more than 3 feet deep is ordinarily 15 to 25 rods per day, depending largely upon soil conditions. In some sections of the country, where the use of unskilled colored labor is necessary, the same number of men will put in, even with good supervision, only 5 to 8 rods per day per man; the cost for this labor per man is, of course, considerably less than for the other.

It should be stated that there is not a great difference in the cost of trenching, as between handwork and machine work. The advantages of the latter method lie in the shorter time required to install drains and in the less difficulty in securing the few workmen

[3] Data collected by J. R. Haswell, former drainage engineer, Bureau of Public Roads.

wanted. Men capable of satisfactorily operating a trenching machine can usually be found, even where it is impossible to secure workmen to do acceptable hand trenching without close and constant supervision. On the other hand, a farmer buying an expensive machine to do a small amount of work might experience some difficulty in keeping it busy with profit until it can be sold.

SELECTING A TRENCHING MACHINE

The wheel type of excavator is most generally used for installing farm drains, probably owing to a lower cost for the smaller sizes of this type than for the chain type. Machines of the latter kind have greater range in size of trench than do wheel excavators of the same weight, and seem to be better adapted for work where there is a great deal of tile 10 inches and larger. When the greater portion of a job is small tile at ordinary depths, that trenching machine should be selected which will handle best the bulk of the work. Ordinarily it is not advisable to buy a large machine when only a few hundred feet of large tile are to be laid or a small amount of deep trench is to be cut.

The weight of the excavator is important in digging soft earth, and may require the use of apron tractors instead of the less expensive wheels. Sometimes internal-combustion engines are preferred to steam equipment because they weigh less. Internal-combustion engines are also quite popular for the smaller machines because the number of men required for operation is less, but they are not so dependable for continuous operation as are steam engines.

A trenching machine should be constructed of good materials and be well proportioned for strength. Simplicity of construction is desirable. The great loss of time on a job due to faulty operation of internal-combustion engines, and to delays for repairing broken chains, bolts, gears, and other pieces, requires the elimination of as many parts as practicable. The cost of repairs depends a great deal upon the skill and care of the operator.

In selecting any type of machine the prospective purchaser should ascertain whether the manufacturer will be able to furnish repair parts on short notice, as delays in obtaining repairs will invariably increase the cost of operation and oftentimes materially lengthen the time of operating.

While it is manifestly impracticable to make a hard-and-fast rule which the landowner may apply in selecting a trenching machine for his particular needs, the following general statements may be of assistance:

If a landowner expects to install 100 rods of tile drain in soil which would require picking, but which contains no rock, he would be justified in buying a ditching plow costing as much as $20. If he proposes to construct 1,500 rods of tile drain in soil free from rock and large roots, the landowner can well afford to purchase a horse-drawn ditching plow costing from $300 to $500; and if it be assumed that the owner can sell his machine, when his ditching is completed, for $200, he would be justified in purchasing such a machine for the construction of 1,000 rods of drain. For the installation of as much as 5,000 rods of drain in a soil free from rock, stumps, and large roots, the purchase of a power-driven trenching machine costing as much

as $3,500 probably would be justified, on the assumption that the machine could subsequently be sold for one-half its original cost. Very economical results may be obtained where several landowners unite in the purchase of such a trenching machine as is most suitable for their combined work. The machine should preferably be run by the same operator for all the work.

Machines costing over $7,000 are suitable for contractors, owners of large plantations, and others having an unusual amount of trenching to do.

Trenches should not be dug any wider than necessary, as increased width means increased load which the tile must carry. The width of trenches dug by the wheel and endless-chain types can usually be regulated as desired. The smallest width of trench dug by drag-line excavators sometimes used in tile-trench construction is limited to the width of the bucket. This is much wider than usually is needed and consequently the supporting strength of the tile must be ascertained if machines of this type are used.

CONCLUSIONS

In comparing the real costs of different machines and implements one must consider not only the purchase price and the operating cost for fuel, oil, and labor, but also repairs, interest on the investment, and depreciation. The interest on $20 invested in a plow is not large; repairs will cost little, and the implement will last many years. For a $3,500 excavator the interest charge would be $210 per year at 6 per cent, depreciation might be $525 or more per year, and repairs would be considerable. Operating expenses and repair costs depend largely upon the amount of work done, but interest and depreciation continue whether the machine is in operation or stands idle.

On large jobs costly excavators may profitably be employed, but an inexpensive tool may be most economical for work that can well be done a little at a time when men and teams regularly employed on the farm might otherwise be idle. One of the greatest advantages of the large machines, from the farmer's viewpoint, is that the work is done rapidly; from the contractor's viewpoint there is often great advantage in using only a few men, as the employment of large numbers often involves labor difficulties.

Work is slow and costly in caving soil, in quicksand, and in sticky gumbo. Large stones, stumps, and roots cause annoyance and delay, and if in large quantity may make hand spading the cheapest method of excavation.

The data on capacities given on the preceding pages must be used with extreme caution, principally because the kind and condition of the soil and the skill of the operator affect the cost so greatly. The quality of the work also depends upon the carefulness and experience of the operator. Each purchaser must consider the limits of the work he will have to do and the conditions to be encountered, then determine what machine will best meet the requirements as a whole.

WASHINGTON : GOVERNMENT PRINTING OFFICE : 1925